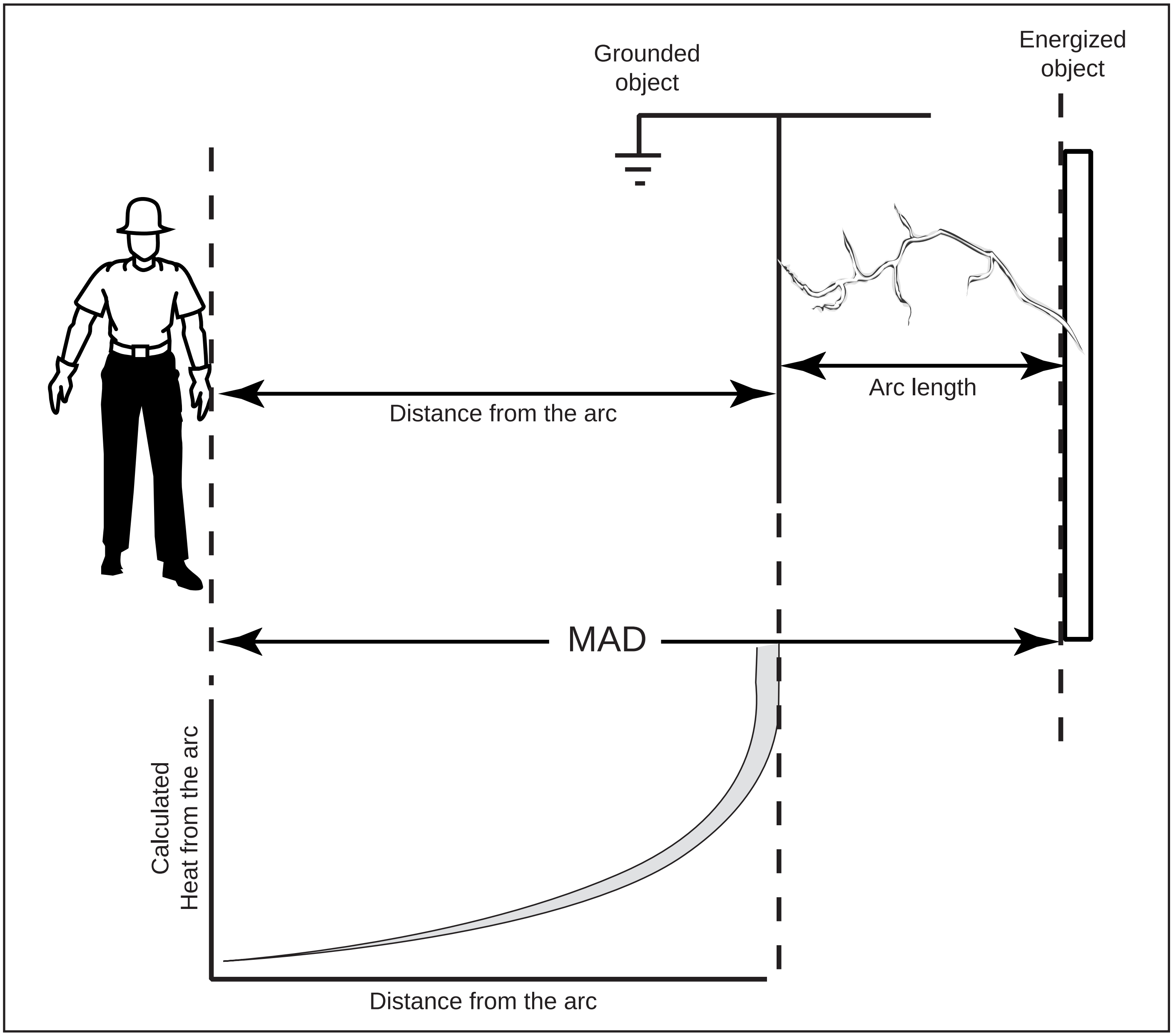
Chapter 14

ARC Flash Exposure Thresholds, Analysis, and Controls

November 2000



Western AREA POWER ADMINISTRATION

Power System Maintenance Manual

Arc Flash Exposure Thresholds, Analysis, and Controls

NOVEMBER 2000

Western Area Power Administration

Power System Maintenance Manual
Chapter 14

Working Publication*

John Quintana
Team Leader, Maintenance

Date

***Will be revised and re-issued one year after publication date.**

Disclaimer

Preface

This guide is issued by the Western Area Power Administration (Western) and is designed to provide specific guidelines, instructions, procedures, and criteria for assessing and mitigating the arc hazard exposure near energized transmission lines and equipment. Procedures and guidelines are in accordance with Western's Power System Safety Manual (PSSM). Corrections or comments concerning this guide may be addressed to:

Western Area Power Administration
Attn: A3900, CSO Maintenance
P.O. Box 281213
Lakewood, Colorado 80228-8213

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1. General

1.1 Purpose. The purpose of this chapter is to define the maximum (acceptable) level of heat, generated from an arc-blast, that a worker can be exposed to, and be in compliance with Western's Power System Safety Manual. This chapter also provides a means of quantifying and determining the maximum level of heat that a worker is exposed to in the event of an arc fault at the work site based on Western's maintenance procedures. All work within close proximity to energized equipment requires knowledge of the level of arc hazard exposure.

1.2 Definitions.

Arc Current – This is the r.m.s. value of the current in the arc.

Arc Duration – This is the time span of the arc from initiation to extinction, specified as a number of cycles of 60 Hz current.

Arc Energy – The total energy discharged to the surrounding space by an electric arc.

Arc Gap – The length of the arc, or distance between the arc electrodes.

Arc Thermal Protective Value – The arc thermal protective value (ATPV) for a piece of clothing is the minimum incident thermal energy that causes the onset of a second degree burn based on the energy transmitted through the clothing.

Close Proximity Distance – Based on the voltage of an energized piece of equipment, this distance is less than or equal to the minimum approach distance to live parts for non-electrical workers, but not less than the minimum approach distance to live parts for electrical workers.

Clothing Weight – The weight of material making up the clothing that is worn by the employee, measured in ounces per square yard (OPSY).

Cycle – One cycle equals 1/60 of a second.

Heat Flux – The thermal intensity of the arc that is incident by the amount of energy transmitted per unit area and per unit of time, measured in calories per square centimeters per second (Cal/cm^2/sec).

Ignition Threshold – The minimum value (associated with an accepted low probability) of heat energy at which a material will reach ignition temperature and start to burn.

Incident Heat – The value of energy that is measured (in calories) on the receiving surface.

Primary Fault Clearing – The fastest time a fault clears, in cycles, based on zone 1 relaying.

Secondary Fault Clearing – The time a fault clears, in cycles, based on zone 2 relaying (aka backup clearing time).

Trigger Current – The amount of current present in an arc that is required to generate enough heat to reach the ignition threshold of the clothing worn by the employee exposed to the arc. System fault currents above this value will "trigger" an additional evaluation. Currents below this value are considered as "reasonable exposure".

1.3 Interpretations.

May – Permissive choice ("may" equals "is permitted").

Shall or Must – Mandatory under normal conditions ("must" or "shall" equals "is required to".

Will – Mandatory, but allowing the responsible employee or party some discretion as to when, where and how.

Should – Advisory. "Should" statements represent the best advise available at the time of printing ("should" equals "is recommended that").

2. Regulatory Requirements

2.1 Background. A memorandum of interpretation from D.O.L. Deputy Assistant Secretary, dated 8/10/95 states that cotton clothing is permitted if the following two conditions hold true:

- The employer has determined that the possible electric arc exposure is less than that posed by an 3,800 ampere arc that is 12 inches long and 12 inches away from the employee and lasts for 10 cycles (1/6 of a second); and

- The clothing being worn will not ignite under the electric arc or flame conditions to which the employee could be exposed.

Since some maintenance activities have the potential to place workers in the vicinity of an arc flash, all locations where maintenance is performed in the vicinity of live parts must be evaluated to determine the maximum potential level of exposure to the arc flash (heat received from the arc flash). The maximum potential level of exposure (measured in calories per square centimeter) shall not be greater than 4.6 calories per square centimeter.

The figure of 4.6 calories per square centimeters of heat is the amount of heat that is required to ignite the minimum weight of clothing that can be worn by an employee (refer to Table 2.1). Table 2.1 shows the 10% probability of ignition at a 95% confidence level for various weight cotton fabrics.

The level of exposure is based on four parameters indicated in the above mentioned memo; arc length, arc duration, distance from the arc, and the current magnitude in the arc. Each work location has an assumed arc length (based on the voltage), an assumed distance away from the arc (based on the work practices), and an assumed arc duration (based on system relaying). Given these assumptions, a current magnitude can be calculated that will generate 4.6 calories per square centimeters of heat. The calculated value for the current is referred to as the “trigger current”.

Table 2.1 – Ignition Threshold for Cotton Fabrics.

Fabric Description				Ignition Threshold (Cal/cm^2)
Weight	**Color**	**Weave**	**Material Type**	
5.2	Blue	Twill	Shirt	4.6
6.2	White	Fleece	Shirt	6.4
6.9	Blue	Twill	Shirt	5.3
8.0	Black	Twill	Shirt or Pants	6.1
8.3	White	Sateen	Shirt or Pants	11.6
11.9	Tan	Duck	Shirt or Pants	11.3
12.8	Blue	Denim	Jeans	15.5
13.3	Blue	Denim	Jeans	15.9

2.2 Prohibited Material. Wearing clothing that contains acetate, nylon, polyester, or rayon, either alone or in blends is prohibited unless it is worn in a manner that eliminates the hazard involved. Hazards that exist during the wearing of prohibited material stated in the OSHA letter of interpretation include the following:

- If the layer of clothing made from a prohibited material is worn as the outside layer of clothing, there is a hazard that the fabric could ignite and burn the employee’s face. Continued burning, likely, would burn other parts of the employee’s body at some point.

- If a layer of clothing made from a prohibited material is worn as a middle layer of clothing, and if enough heat passed through the outer layer(s), there is a hazard that the fabric also could ignite (assuming sufficient air flow).

- If a layer of clothing made from a prohibited material is worn as the inside layer of clothing, there is a hazard that the fabric could melt in contact with the employee's skin thereby causing a burn injury.

The employer must be able to demonstrate that a prohibited material worn by an employee does not cause the aforementioned hazards.

2.3 Practice. Protection from arc flash burns is accomplished through various administrative and engineering controls such as performing the work in the deenergized mode or performing work that is not in proximity to energized parts. Administrative and engineering controls are Western's preferred practice for mitigating the arc hazard. The arc hazard In most cases should be considered during the following type of work:

- Switching.

- Work inside battery rooms.

- Grounding Applications.

- Deenergized work on double circuits (one circuit energized).

- Low-voltage maintenance applications.

- Substations; station service, racking breakers.

Work in proximity to energized parts is any work performed by a qualified electrical worker that requires approaching live parts within the distances specified in the Power System Safety Manual, Table A2. While performing work in proximity to live parts, workers shall (as a minimum) be protected from arc flashes to the extent that their clothing will not ignite, increasing the injury that could be sustained.

2.4 Procedure. There are three maintenance procedures where engineering and administrative controls must be closely assessed to determine if the work practices and procedures adequately protect the worker from the arc exposure hazard. These include 1. hotstick work, 2. barehand work and 3. denergized work that that is in close proximity to energized equipment. For these maintenance practices, specific locations and maintenance procedures must be analyzed to determine if there is sufficient energy to generate 4.6 calories per square centimeters of heat at the worker's location.

3. Arc Exposure Thresholds and Parameters

3.1 High Voltage Work (69 kV and Above). Calculating the amount of heat that is received during an arc flash is dependent on the following five parameters:

- The arc duration.
- The voltage (which directly relates to the working distances, arc duration, and arc gap).
- The arc gap.
- The distance away from the arc.
- The current magnitude (trigger current).

The values of the first four parameters, with regard to existing maintenance practices in Western, are used to calculate the trigger current (last parameter) based on 4.6 calories per square centimeters of heat on the receiving surface. Voltage levels used are those applicable to live line work (69 kV and above).

3.1.1 Arc Duration. In order to determine the arc duration, the main factor that must be considered is the equipment protection (relaying) on the line or bus. For the purposes of this study, fault-clearing times are categorized by voltage and by primary and secondary relaying shown in table 3.1.1.

Table 3.1.1 - Arc Duration

VOLTAGE	Secondary Fault Clearing Times*	Primary Fault Clearing Times*
500 kV	20 Cycles	3 Cycles
345 kV	25 Cycles	4 Cycles
230 kV	35 Cycles	5 Cycles
161 kV	35 Cycles	5 Cycles
136 kV - 115 kV	35 Cycles	5 Cycles
69 kV	45 Cycles	6 Cycles

* **NOTE:** Choosing the appropriate fault clearing time requires knowledge of the system. For substations it is normally appropriate to use primary clearing times based on the amount of protection present for substation equipment. For transmission lines, some sections of the line may only clear through secondary protection. Using values that are Regional specific is also acceptable. An example of this would be transmission lines with pilot protection versus lines with non-pilot relaying. Transmission lines with non-pilot relaying usually provide high speed simultaneous protection for only 70 to 80 percent of the faults in the middle section of the line. For a fault outside this boundary, the terminal nearest the fault would open that end of the line at high speed, and the remote terminal bus will open after a time delay. Therefore, lines with non-pilot relaying may routinely fully clear faults within the times stated in the {secondary fault clearing times" column above.

3.1.2 Arc Gap. Arc gap (length) directly effects the level of heat transferred to a receiving surface; as the length increases, the amount of heat that is transferred increases. It is assumed that as a worker is performing a task, the initial arc is struck when a worker takes a conductive article within the 60 Hz breakdown distance in air. The dielectric strength of air is taken at 10 kV per inch. The calculated arc gap lengths are shown in Table 3.1.2.

Table 3.1.2 - Arc Gap

Line Voltage	Phase to Ground Voltage	Arc Gap (Flashover)
69 kV	40 kV	40 kV / 10 kV = **4 inches**
115 kV	67 kV	67 kV / 10 kV = **7 inches**
138 kV	80 kV	80 kV / 10 kV = **8 inches**
161 kV	93 kV	93 kV / 10 kV = **10 inches**
230 kV	133 kV	133 kV / 10 kV = **14 inches**
345 kV	200 kV	200 kV / 10 kV = **20 inches**
500 kV	318 kV	318 kV / 10 kV = **32 inches**

3.1.3 Distance from the Arc. The primary purpose of the minimum approach distance to live parts (MAD) is to protect workers from electrocution, not for protection from the heat generated in an arc flash. Also, after an arc is initiated, it cannot be confined to a safe distance while the worker is at the MAD. Therefore, the value used for the distance from the arc must be less than the MAD. There are three assumptions made in determining the distances shown in Table 3.1.3:

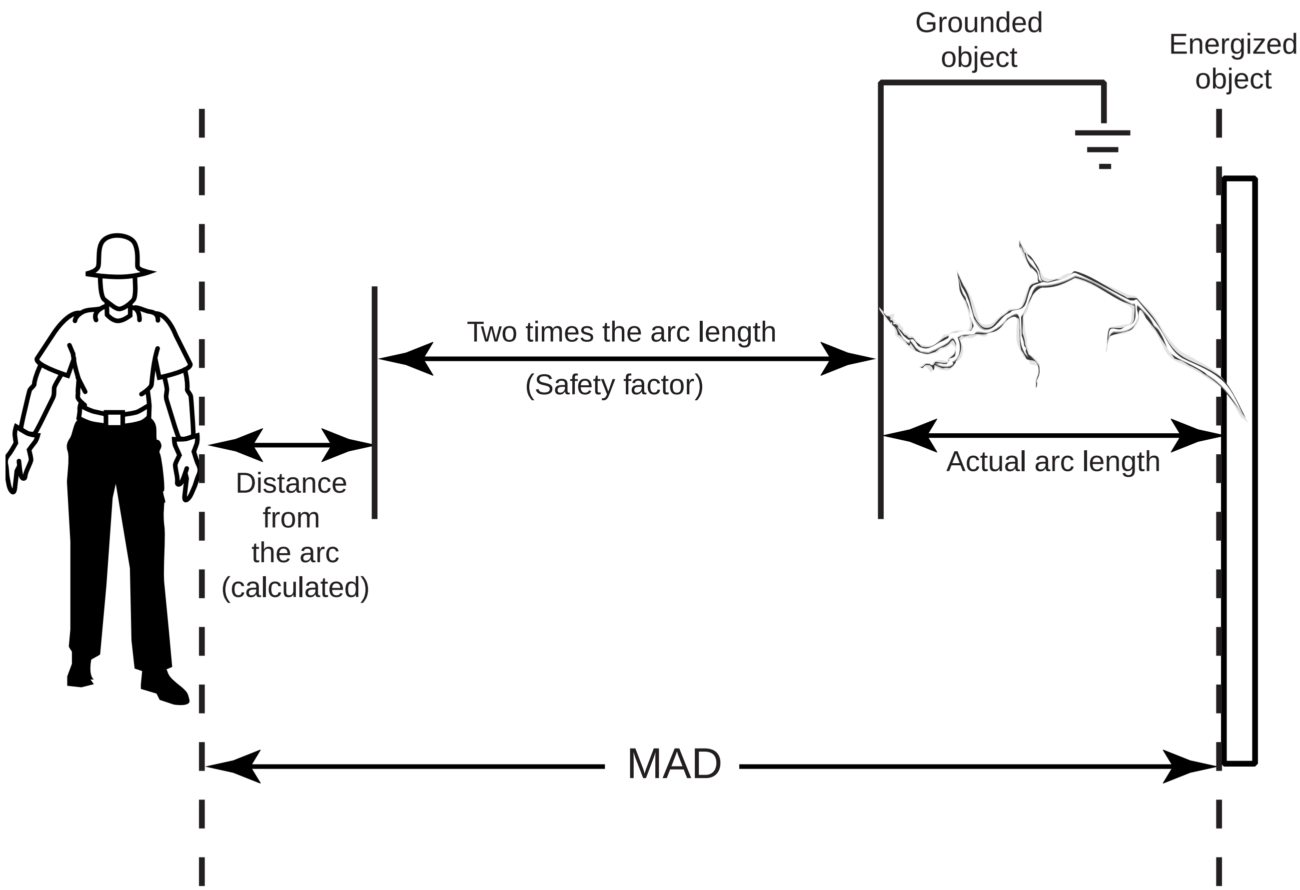
- The MAD would not be violated by the worker's body, and
- The arc will travel directly toward the employee (i.e., the shortest distance between the employee and the arc is assumed).
- The distance between the arc and the employee is the MAD minus two times the assumed arc gap length for the given voltage (refer to Figure 1).

  The last assumption is a safety factor to allow for mechanical failure causing a violation of the MAD.

Table 3.1.3 - Distances from the Arc

Line Voltage	MAD (inches)	Arc Gap (inches)	Distance from Arc
69 kV	39	4	39 inches — 8 inches = **31 inches**
115 kV	38	7	38 inches — 14 inches = **24 inches**
138 kV	43	8	43 inches — 16 inches = **27 inches**
161 kV	48	10	48 inches — 20 inches = **28 inches**
230 kV	63	14	63 inches — 28 inches = **35 inches**
345 kV	102	20	102 inches — 40 inches = **62 inches**
500 kV	135	31	135 inches — 64 inches = **71 inches**

Figure 1. Illustration of Distance Parameters



3.1.4 Calculated Trigger Currents. Using the parameters stated above, the following trigger currents shown in table 3.1.4 were determined using the ARCPRO™ program. The trigger currents listed for each voltage represent the maximum acceptable level of exposure (rounded down to the nearest 100 amperes) for both primary and secondary clearing times. Trigger currents other than those listed below can be used as long as the parameters used to calculate them are verified and documented.

3.1.5 Fault Currents. An initial fault current calculation on all transmission lines and equipment (identified as an arc hazard exposure location) is required and shall be compared with the values in table 3.1.4. as outlined in detail in section 4. Subsequent fault current calculations are only required when a change is made to the system which has an effect on the fault magnitude. The type of fault that is calculated is a single line to ground fault (phase-to-ground). This is based on the assumption that, should a human error or mechanical failure occur during a maintenance procedure, the incident would occur on a single phase (as opposed to two or three phases or phase-to-phase).

Table 3.1.4 - Trigger Currents

Voltage (Ph-Ph)	Distances (inches)	Arc Gap (inches)	Duration (Cycles)	Trigger Current (Amperes)
69 kV	34	4	45 (secondary)	11,800
			6 (primary)	47,700
115 kV	29	7	35 (secondary)	7,100
			5 (primary)	32,400
138 kV	32	8	35 (secondary)	8,200
			5 (primary)	36,800
161 kV	36	10	35 (secondary)	7,300
			5 (primary)	37,300
230 kV	46	14	35 (secondary)	8,000
			5 (primary)	40,900
345 kV	72	20	25 (secondary)	20,700
			4 (primary)	88,100
500 kV	93	32	20 (secondary)	26,300
			3 (primary)	>100,000

3.2 Low Voltage Work (Below 69 kV). Some low voltage work (voltages 46 kV and below) must be performed in close proximity to energized equipment. This may include work in energized panels, station service transformers, or on rack-type breaker installations. A major difference between low voltage work and transmission line work is the fault location. Section 3.1 assumes that all arc flashes occur in an open location (360 degree exposure) rather than in an enclosure such as a panel or cubicle. Testing performed with arcs in enclosures has shown incident heat levels will increase from 150% to 300%, based upon the geometry of the enclosure, versus the same energy level in a 360 degree arc exposure. For the purpose of calculating trigger currents to compare with fault currents, the acceptable level of heat generated in an arc flash can be categorized into 4 levels dependent on the geometry of the surrounding area of the fault location shown in table 3.2.

3.2.1 Arc Duration. Low voltage faults on equipment either have relay protection or fused (over current) protection. Relays will provide the same fault clearing times indicated in table 3.1.1 while fused protection will clear faults within 6 cycles. Therefore, as a worst case estimate, a 6 cycle clearing time will be used for all (low voltage) faults within a substation.

Table 3.2 - Fault Location Category (Low Voltage)

Fault Location Category	Geometry of Location	Maximum Calculated Acceptable Heat Transfer (calories per cm^c)
I (no increase)	Open (360 degree exposure)	4.6
II (100% increase)	One side covered (180 degree exposure)	2.3
III (200% increase)	Two sides covered (90 degree exposure)	1.53
IV (300% increase)	Three sides covered (maximum exposure)	1.15

3.2.2 Arc Gap. The length of an arc in low voltage areas is more of a function of the fault's surroundings than the voltage itself. Air breakdown would determine the initial arc length, however, since most low voltage areas are in close quarters (to grounded objects), it is likely the arc will move (elongate) toward other grounded objects before relays or fuses can clear the fault. As a worst case estimate, based on NEC design requirements and the American Electrician's Handbook, the minimum distance between live parts and grounded objects is shown in table 3.2.2. These distances are based on a safety factor of 3 between live parts and ground.

Table 3.2.2 Minimum Distance between Live Parts and Ground

Voltage	Minimum Distance (Assumed Arc Gap)
36 kV to 46 kV	13.5 inches
15.1 kV to 36 kV	10 inches
.751 kV to 15 kV	3.75 inches
301 to 750 Volts	1.5 inches

3.2.3 Distance from the Arc. The MAD for voltages 46 kV and below is actually more conservative than high voltage MADs due to an inadvertent movement factor of two feet (for voltages 69 kV to 750 V). However, when in enclosed spaces, we should assume that the arc will likely travel toward the employee (worst case), encroaching on the MAD. Therefore, the assumed distance from the arc for low voltage energized work is the MAD, minus the arc length (refer to Table 3.2.3).

Table 3.2.3 - Distance from the Arc

Line Voltage	MAD (inches)	Arc Gap (inches)	Distance from Arc
36 kV to 46 kV	33	13.5	33 inches — 13.5 inches = **19.5 inches**
15.1 kV to 36 kV	31	10	31 inches — 10 inches = **21 inches**
.751 kV to 15 kV	26	3.75	26 inches — 3.75 inches = **22.25 inches**
301 to 750 Volts	12	1.5	12 inches — 1.5 inches = **10.5 inches**

3.2.4 Calculated Trigger Currents. Using the parameters stated above, the following trigger currents shown in tables 3.2.4A through 3.2.4D were determined using the ARCPRO™ program. The trigger currents listed for each voltage represent the maximum acceptable level of exposure (rounded down to the nearest 100 amperes) for both primary and secondary clearing times. Trigger currents other than those listed below can be used as long as the parameters used to calculate them are verified and documented.

Table 3.2.4 A - Category I Trigger Current Levels

Voltage (Ph-Ph)	Distances (inches)	Arc Gap (inches)	Duration (Cycles)	Trigger Current (Amperes)
36 kV to 46 kV	19.5	13.5	6	14,100 (less than 4.6 cal/cm^2)
15.1 kV to 36 kV	21	10	6	20,200 (less than 4.6 cal/cm^2)
.751 kV to 15 kV	22.5	3.75	6	32,300 (less than 4.6 cal/cm^2)
301 to 750 Volts	10.5	1.5	6	17,300 (less than 4.6 cal/cm^2)

Table 3.2.4 B - Category II Trigger Current Levels

Voltage (Ph-Ph)	Distances (inches)	Arc Gap (inches)	Duration (Cycles)	Trigger Current (Amperes)
36 kV to 46 kV	19.5	13.5	6	7,800 (less than 2.3 cal/cm^2)
15.1 kV to 36 kV	21	10	6	11,200 (less than 2.3 cal/cm^2)
.751 kV to 15 kV	22.5	3.75	6	20,100 (less than 2.3 cal/cm^2)
301 to 750 Volts	10.5	1.5	6	10,800 (less than 2.3 cal/cm^2)

Table 3.2.4 C - Category III Trigger Current Levels

Voltage (Ph-Ph)	Distances (inches)	Arc Gap (inches)	Duration (Cycles)	Trigger Current (Amperes)
36 kV to 46 kV	19.5	13.5	6	5,600 (less than 1.53 cal/cm^2)
15.1 kV to 36 kV	21	10	6	7,900 (less than 1.53 cal/cm^2)
.751 kV to 15 kV	22.5	3.75	6	15,000 (less than 1.53 cal/cm^2)
301 to 750 Volts	10.5	1.5	6	8,100 (less than 1.53 cal/cm^2)

Table 3.2.4 D - Category IV Trigger Current Levels

Voltage (Ph-Ph)	Distances (inches)	Arc Gap (inches)	Duration (Cycles)	Trigger Current (Amperes)
36 kV to 46 kV	19.5	13.5	6	4,500 (less than 1.15 cal/cm^2)
15.1 kV to 36 kV	21	10	6	6,300 (less than 1.15 cal/cm^2)
.751 kV to 15 kV	22.5	3.75	6	12,100 (less than 1.15 cal/cm^2)
301 to 750 Volts	10.5	1.5	6	6,600 (less than 1.15 cal/cm^2)

3.2.5 Fault Currents. An initial fault current calculation on only those busses and equipment where there is potential exposure to an arc flash shall be compared with the values in the appropriate table above (depending on the geometry of the surrounding area – 3.2.4 A, B, C, or D). This comparison analysis is outlined in detail in section 4. Subsequent fault current calculations are only required when a change is made to the system that may have an effect on the fault magnitude. The type of fault that is calculated is either a phase to ground or phase to phase (which ever is higher) due to the configurations being closer together.

4. Arc Flash Exposure Analysis

4.1 Requirements. An initial arc flash exposure analysis is required for the following lines and equipment:

- Transmission lines and equipment where live work is performed (hotstick and barehand).
- All deenergized equipment where the maintenance is performed in close proximity to energized equipment, such as in substations.
- Low voltage equipment that requires work in close proximity to energized parts.
- Station service transformers where there are exposed energized parts.

The analysis must document the level of exposure, either in the form of a fault current or the actual heat exposure measured in calories per square centimeter. A flow chart of the procedure for performing an arc exposure analysis is shown in figure 4.1.

4.2 Initial (General) Fault Study. Initially, perform a fault study on all transmission lines, substation busses, and equipment identified above to determine the magnitude of available fault current under the system conditions that the worker will be performing work in close proximity to exposed energized parts. The conditions require the entire system energized and intact (interconnected). The type of fault used in this study is a phase to ground fault. Updates to the fault study are only required for specific lines, busses, and equipment that may yield a different fault magnitude due to a system change (new equipment, interconnection, addition, etc.). Refer to Figure 4.1.

4.3 Transmission Line Trigger Current Comparison. Compare the fault study currents with the appropriate trigger currents listed in Sections 3.1.4 or 3.2.4 (depending on the voltage). Transmission lines that have a fault current magnitude less than the trigger current (in the initial, secondary, or specific comparisons below) indicate the worker is protected from arc flash hazards (to the extent that clothing will not ignite). The protection is provided by existing engineering and administrative controls (system relaying and observing the proper minimum approach distances to live parts).

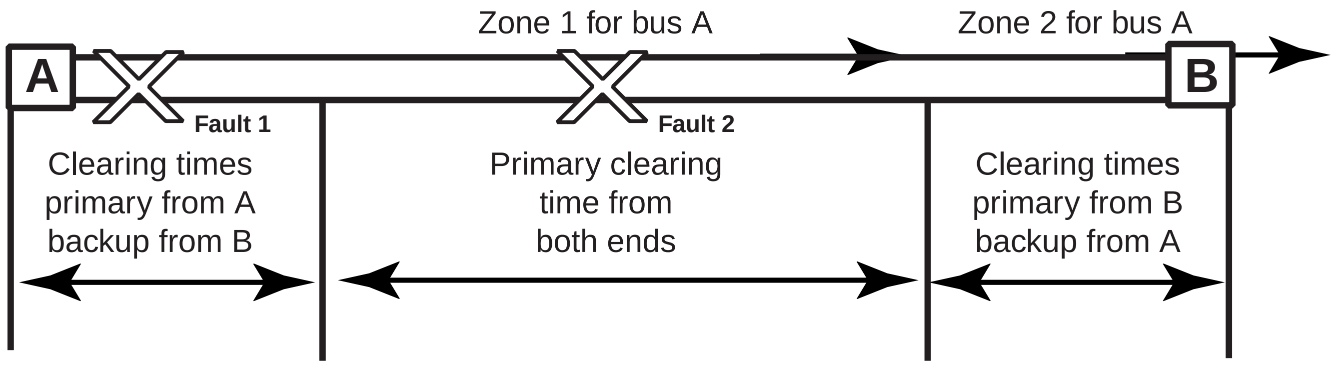
4.3.1 Initial Comparison. Compare the fault study currents with secondary clearing trigger currents in table 2.4 (trigger currents based on backup or zone 2 clearing times). This initial comparison will immediately eliminate several lines from the total list of equipment to be further analyzed. This is a comparison of the worst case exposure of each line with the maximum acceptable exposure of 4.6 calories per square centimeter. This step is depicted as block 3 in figure 4.1.

4.3.2 Secondary Comparison. For transmission lines with pilot relaying and having fault current magnitudes greater than the secondary clearing trigger currents, compare their fault current with the primary clearing trigger currents in table 2.4.

4.3.3 Actual Exposure Comparison. For transmission lines without pilot relaying and having a fault current magnitude greater than the secondary clearing trigger currents, but less than the primary clearing trigger currents, an actual comparison of heat exposure should be conducted.

For transmission lines, the zone 1 relays (on terminal A, figure 4.3.3) typically “look” 80% of the way toward the remote terminal (terminal B). For Fault 1, zone 1 relays will clear at terminal A in the primary clearing time. Zone 2 relays will “look” past the remote terminal and clear terminal B in the backup clearing time.

Figure 4.3.3. Relay Fault Clearing Zones



Calculating the actual incident heat exposure for the remote ends of the line is only necessary for lines without pilot relaying. This calculation is done in two parts (identified as step 11 in the figure 1 flowchart). For the middle part of any line (approximately 60%) faults are cleared in the primary clearing time (refer to Fault 2 in Figure 4.3.3). For the portion of each line (approximately 20%) closest to each terminal, faults such as fault 1, will be cleared in the primary clearing time by the relay at the bus closest to the fault (bus A). However, the fault will still be fed from the remote bus (bus B) until the backup clearing time. This results in a two-stage fault. During the primary clearing time the fault magnitude will be higher, because it is being fed from both ends. Once the near bus clears, the fault reduces, but continues at a lower level until the remote bus clears. The current levels during each part of the fault must be considered separately; each for its portion during the total fault duration. The calculated heat for each portion is then added to see if the total energy is enough to reach the value of 4.6 cal/cm^2.

4.4 Substations Trigger Current Comparison. For substation busses (outside work in substation yards) compare the fault study currents with the primary clearing trigger currents in table 2.4 (trigger currents based on high speed clearing times). The primary clearing trigger currents are applicable due to the amount of protection that is present for substation equipment. Substation busses and equipment that have a fault current magnitude less than the trigger current indicate that the worker is protected from arc flash hazards (to the extent that the worker's clothing will not ignite). The protection is provided by existing engineering and administrative controls (system relaying and observing the proper minimum approach distances to live parts).

4.5 Low Voltage Trigger Current Comparison. For low voltage work, compare the fault study currents with the appropriate trigger current in table 3.4 A, B, C, or D (based on the location/geometry of the exposed energized equipment). Low voltage areas that have a fault current magnitude less than the trigger current indicate that the worker is protected from arc flash hazards (to the extent that the worker's clothing will not ignite). The protection is provided by existing engineering and administrative controls (system relaying and observing the proper minimum approach distances to live parts).

4.6 Documentation. Document and file the phase to ground fault study and the comparison listing the lines, busses and equipment that have fault current magnitudes less than the trigger current values. For this equipment, no further action is needed, no change in work procedure is required, no additional protective apparel is required. Follow the established work procedures and safety requirements.

4.7 Levels of Exposure. Any transmission line, substation equipment, or low voltage equipment having a fault current magnitude greater than the applicable trigger current or a level of heat exposure greater than 4.6 Cal/cm^2 is considered unacceptable. This indicates that established engineering and administrative controls currently in place are ineffective in preventing clothing ignition. Section 5 outlines several options that can be used for removing or reducing the arc hazard exposure to an acceptable level.

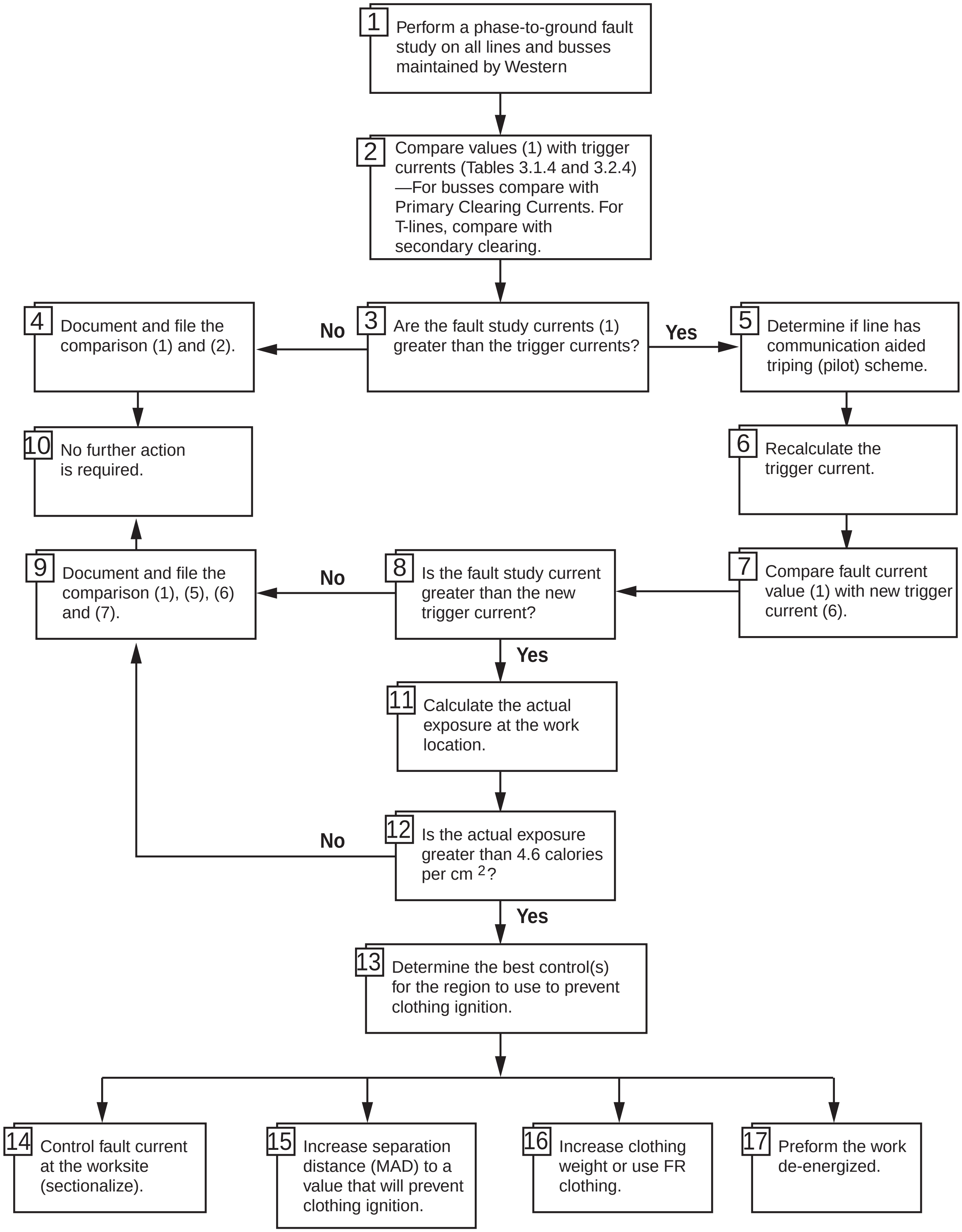


Figure 4.1 - Arc Flash Exposure Analysis Procedure

5. Arc Exposure Controls

As shown in figure 4.1 there are four options are available to avoid or reduce the arc exposure hazard to an acceptable level which will require a change in work procedure or practice (blocks 14 through 17).

5.1 Operational Controls. Since fault current magnitude depends on the resistance of a line or bus, there are operational methods that can be used to provide control over this factor. If the fault current can be controled to a level that is less than the trigger value, then the work procedure may only require switching (to sectionalize) at the substation(s) prior to performing live maintenance. This procedure requires close coordination with operations (to determine what switching can be performed) and system studies (what is the resultant fault current).

5.2 Working Distance Controls. Since the distance from the arc is a function of the amount of heat transfer, the minimum approach distance to live parts (which was used to calculate the initial trigger current in step 2) can be increased to a distance which will prevent clothing ignition. The practice of increasing the MAD is also performed while working in proximity to energized parts at elevations greater than 3000 feet above sea level so although this is a change in work procedure, it is not a foreign practice.

5.3 Flame Resistant Clothing. Use clothing that will not ignite under the conditions that the worker could be exposed. The initial trigger current calculated in step 2. assumes the worker will be in a t-shirt weight cotton material. Under all conditions (at any level of fault current magnitude) flame resistant clothing is acceptable under current OSHA regulations. If the worker uses clothing that is not flame resistant, the clothing that is worn must match the hazard (i.e., Is the magnitude of the fault current greater than the trigger current for 8 or 12 oz cotton? If the fault current magnitude is high enough to ignite 4 oz but not 8 oz, then the work must be conducted using a minimum of 8 or 12 oz cotton apparel). In any case, if the magnitude of the fault current exceeds the trigger current for 12 oz cotton, the work must be performed wearing some type of flame resistant apparel (Nomex, Endura, PBI, etc.).

5.4 De-energized Work. As a minimum, lines and substations that are routinely worked deenergized should continue to be worked deenergized. The remaining lines that cannot be taken out of service should be identified and be the focus of this analysis.

6. Cold Weather Clothing

6.1 Requirements. Typical cold weather clothing is composed of an outer shell with an inner insulated lining. The insulated lining in a majority of cold weather clothing is made from prohibited material (polyester, nylon, rayon or acetate). Wearing cold weather gear containing prohibited material (when working in close proximity to energized equipment) is allowed with restrictions, specifically with how it is to be worn. These restrictions include:

- The clothing must have an outer shell made of 11oz or greater cotton or wool.
- The outer shell must fully “protect” the prohibited material while the employee is working in close proximity to energized equipment.

These restrictions, should also apply to construction work (contracts), and foreign utilities entering our substations that will be working under conditions exposing them to the arc hazard.

Requiring the use of fire resistant (FR) rated cold weather gear for personnel working in close proximity to energized equipment sufficiently addresses the hazard. By wearing FR cold weather gear, no other restrictions would apply and compliance with the current regulations would be accomplished.

6.2 Procedures. The use of FR rated cold weather gear is required for work in proximity to energized equipment. Specifically during barehand work, hotstick work, switching, and substation work (under a clearance) when performed in close proximity to energized equipment.

Work that would not require the use of FR rated cold weather/rain gear would include the following:

- All work under a clearance outside the close proximity distance to energized equipment, or
- observing work (such as in a substation) outside of distances defined in the PSSM Appendix B Table B1, or
- walking through a substation (not performing any work).